Stillwater Sciences

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# Technical Memorandum

**Date:** September 6, 2007
**To:** Mr. Michael Bowen, Project Manager
**From:** Yantao Cui, Ph.D., Hydraulic Engineer, and Bruce Orr, Ph.D., Senior Ecologist and Principal
**Re:** A first-order estimate of fine sediment trapping potential within Iron Gate Reservoir for upstream drawdown and dam removal

## 1. Introduction

This memorandum provides a first-order analysis of fine sediment trapping potential within Iron Gate Reservoir if the upstream dams (i.e., J.C. Boyle, Copco 1 and 2) are removed while keeping Iron Gate Reservoir in place to trap the fine sediment released from the upstream reservoirs.

## 2. Method

The analysis adopts the following approach to estimate whether a sediment particle of specific diameter will likely settle to the bottom of the reservoir before it reaches Iron Gate Dam: we assume that a suspended sediment particle will travel downstream with the same velocity as the cross-section-averaged flow velocity, and at the same time, it will move downward toward the reservoir bottom with a velocity identical to its settling velocity. If a sediment particle settles to the reservoir bottom before it travels to the dam, it will likely be trapped in the reservoir, otherwise it will likely pass through the dam to the downstream reach.

## 3. Analysis and results

*Water Discharge*

It is reasonable to assume that Iron Gate Reservoir has to be able to trap the majority of the fine sediment released from the reservoir deposits behind upstream dams during their removal in order to implement a phased removal alternative that uses Iron Gate Reservoir for sediment trapping. With that, we can assume that the upstream reservoir drawdown and dam removal can occur during the summer low flow season when Iron Gate Reservoir water level can be kept in a high elevation and the incoming flow is low. This combination will ensure that Iron Gate Reservoir is managed to provide the most efficient trapping of the incoming sediment. Analysis of the long-term discharge record at Klamath River below Iron Gate gauging station (USGS #11516530) indicates that average discharge in the months of June, July and August is usually around 28 $m^3/s$ (1,000 cfs). If Copco 1 Reservoir can be drawn down at a rate that releases 14 $m^3/s$ (500 cfs) of extra water, the combined discharge entering Iron Gate Reservoir will be approximately 42 $m^3/s$ (1,500 cfs). Note that releasing 14 $m^3/s$ of extra water from Copco 1 Reservoir will allow for the 32 million $m^3$ (26,000 acre-ft) of reservoir storage to be emptied in approximately 26 days. Increasing the release rate from Copco 1 will reduce the trapping efficiency of Iron Gate Reservoir, allowing more fine sediment to pass Iron Gate Dam to the downstream reach.

In the analysis provided below, we use the 42 $m^3/s$ (28 $m^3/s$ natural contribution, plus 14 $m^3/s$ from Copco 1 Reservoir drawdown) as the discharge in Iron Gate Reservoir.

*Time needed for a sediment particle to pass through Iron Gate Reservoir*

In order to estimate the time needed for a sediment particle to pass through Iron Gate Reservoir, we cut out 15 cross sections from the Iron Gate Reservoir bathymetry map provided in Eilers and Gubala (2003). Cross section areas are calculated for an Iron Gate Reservoir pool level of 709 m (2,326 ft) and are presented in Figure 1 along with the depth along the thalweg of the reservoir. We than used the above data to calculate cross-section-averaged flow velocity at a discharge of 42 $m^3/s$, and the results are presented in Figure 2. Assuming suspended sediment particles travel downstream at the same velocity as the cross-section-averaged flow velocity, the time needed for a suspended sediment particle to pass between cross sections and from entering the reservoir to reach a cross section is calculated and presented in Figure 3. Based on Figure 3, a suspended sediment particle will take approximately 362,000 seconds (approximately 100 hours) to reach the dam once it enters the reservoir.

*Critical settling velocity for suspended sediment to settle to the bottom of the reservoir*

If a suspended sediment particle settles to the bottom of the reservoir, it will likely be trapped in the reservoir. If it does not settle on the reservoir bottom, the particle will pass through the dam and continue to travel downstream. The critical settling velocity is calculated by dividing the water depth at a location by the time needed for the particle to reach the location after it enters the reservoir, i.e., by dividing the depth shown in Figure 1 with the cumulative time shown in Figure 3. The calculated critical settling velocity is presented in Figure 4. The minimum critical settling velocity shown in Figure 4 is approximately 0.00011 m/s.

*Potential sediment trapping in Iron Gate Reservoir*

Assuming a specific gravity of 2.65 for sediment particles, the critical suspended sediment particle size associated with the 0.00011 m/s critical settling velocity is calculated based on the procedure outlined in Dietrich (1982) as 0.011 mm. That is, particles coarser than 0.011 mm will likely settle in Iron Gate Reservoir while particles finer than 0.011 mm will likely pass through Iron Gate Dam to the downstream reach. The fraction of sediment that is finer than 0.011 mm in Copco 1 and J.C. Boyle reservoirs (Copco 2 Reservoir has no sediment deposit) is not available. Grain size distributions for sediment cores obtained from Copco 1 Reservoir by Shannon and Wilson, Inc. (2006), however, are available as presented in Figure 5. Note in Figure 5 that the red vertical line denotes the critical particle size for settling in Iron Gate Reservoir as calculated above, and it can be observed that substantial fraction of fine sediment is on the left side of this red vertical line, indicating a large fraction (generally 20-90%, except a few cores) of fine sediment will be passing Iron Gate Dam to the downstream reach. This result confirms Mr. Dennis Gathard's early conclusion that a significant fraction of fine sediment will pass Iron Gate Dam if Iron Gate Reservoir is used for sediment trapping during phased dam removal (Dennis Gathard, personal communication, August 2007).

## 4. Conclusion and discussion

Based on our analysis above, significant fraction of suspended sediment will pass through Iron Gate Dam if Iron Gate Reservoir is used for sediment trapping during phased dam removal, confirming Mr. Dennis Gathard's early conclusions. Three factors not considered in the analysis may significantly increase the amount of fine sediment release: (a) there is considerable amount of organic material in the sediment deposit (Shannon and Wilson 2006), which may be much less dense than the specific gravity of 2.65 used in the analysis, resulting in a much slower settling and thus, significantly increased fine sediment discharge through Iron Gate Dam; (b) flow velocity is not uniformly distributed across the reservoir cross section, and thus, a large fraction of the suspended sediment will travel downstream with the high velocity core much faster than the average velocity assumed in the analysis, leading to less fine sediment settlement; and (c) the high suspended sediment concentration of the flow entering Iron Gate Reservoir may result in the formation of turbidity current (e.g., Parker et al. 1986) that can flow to and pass through the outlet of the dams with very little settling within the reservoir. Whether turbidity current will form in Iron Gate Reservoir is not investigated because we have concluded that significant amount of fine sediment will pass through the dam even without the formation of turbidity current, and the formation of turbidity current will only enhance this conclusion.

**References**


Dietrich, W.E. (1982) Settling velocities of natural particles, *Water Resources Research*, 18(6), 1615-1626.

Eilers, J.M., and Gubala, C.P. (2003) Bathymetry and sediment classification of the Klamath Hydropower Project impoundments, Report prepared for PacifiCorp, 40p, April.

Parker, G., Fukushima, Y., and Pantin, H.M. (1986) Self-accelerating turbidity currents, *Journal of Fluid Mechanics*, 171: 145-182, doi: 10.1017/S0022112086001404.

Shannon and Wilson, Inc. (2006) Sediment sampling, geotechnical testing, and data review report, Segment of Klamath River, Oregon and California, submitted to M. Bowen, California State Coastal Conservancy, 1330 Broadway, 13th floor, Oakland, CA 94612-2530, 18 p + figures/tables/appendices, November 22.

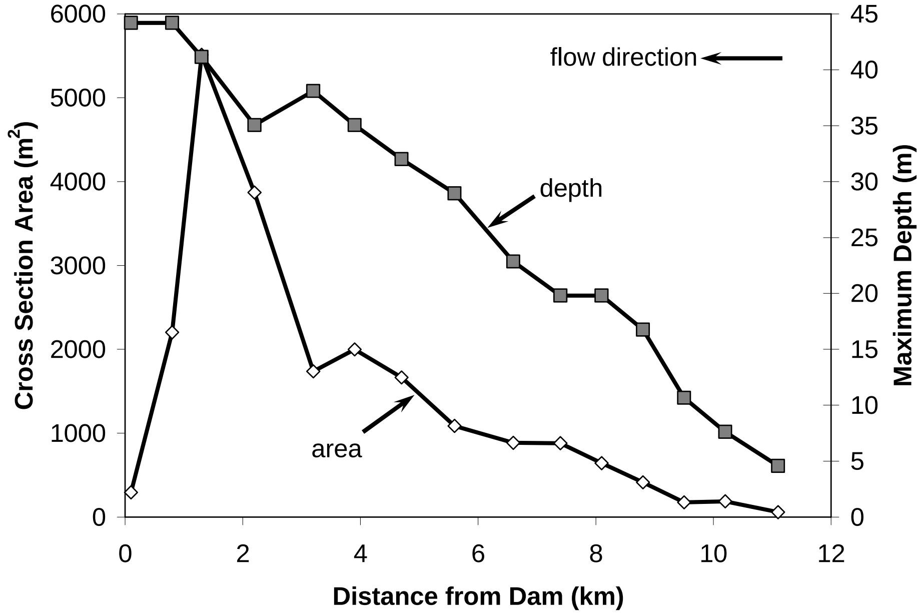


Figure 1. Flow area and maximum water depth in Iron Gate Reservoir at 709 m pool level, based on bathymetric map provided in Eilers and Gubala (2003).

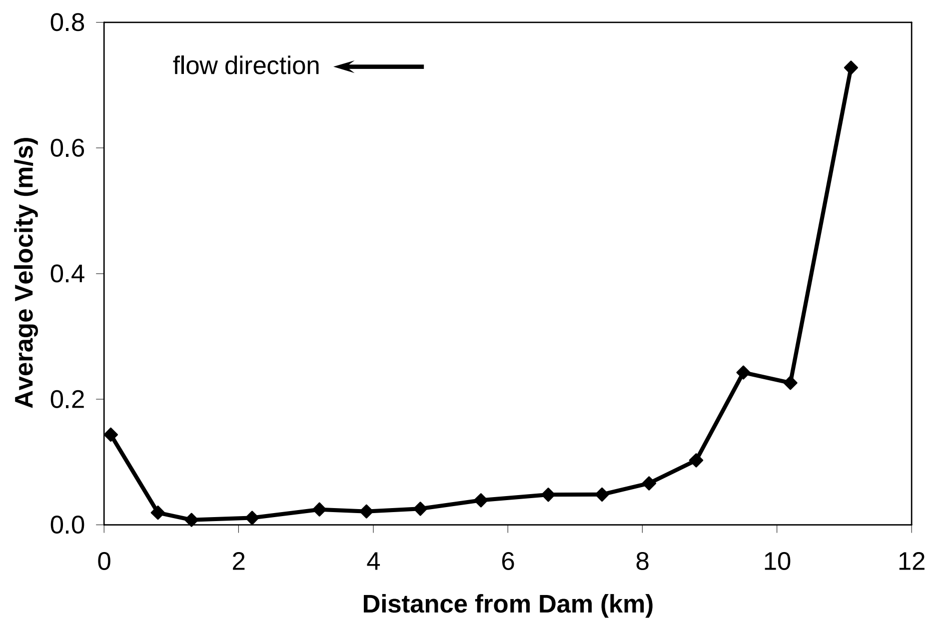


Figure 2. Cross-section-averaged flow velocity in Iron Gate Reservoir at 709 m pool level, based on cross section area presented in Figure 1 and a water discharge of 42 $m^3/s$ (1,500 cfs).

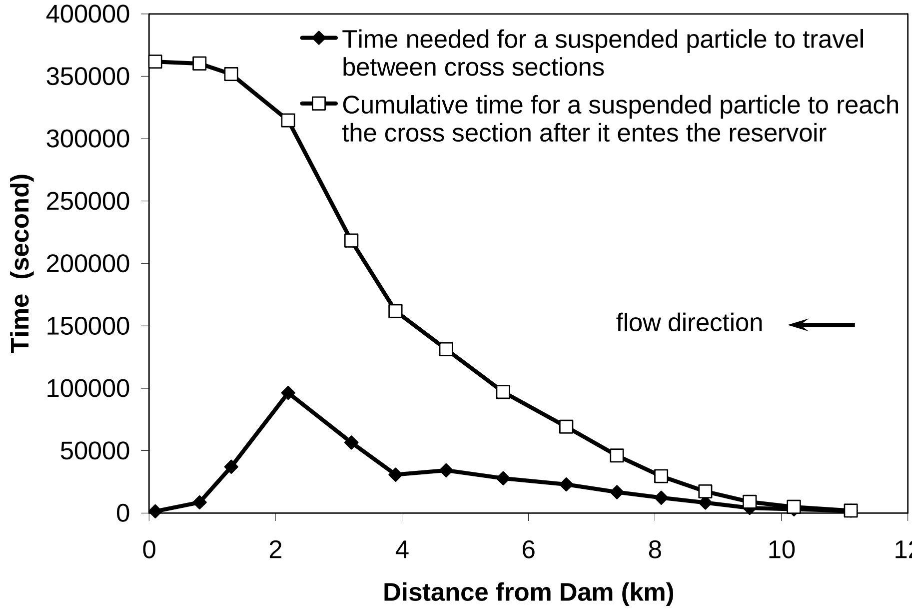


Figure 3. Suspended sediment particle traveling time in Iron Gate Reservoir at 709 m pool level, based estimated cross-section-averaged flow velocity presented in Figure 2.

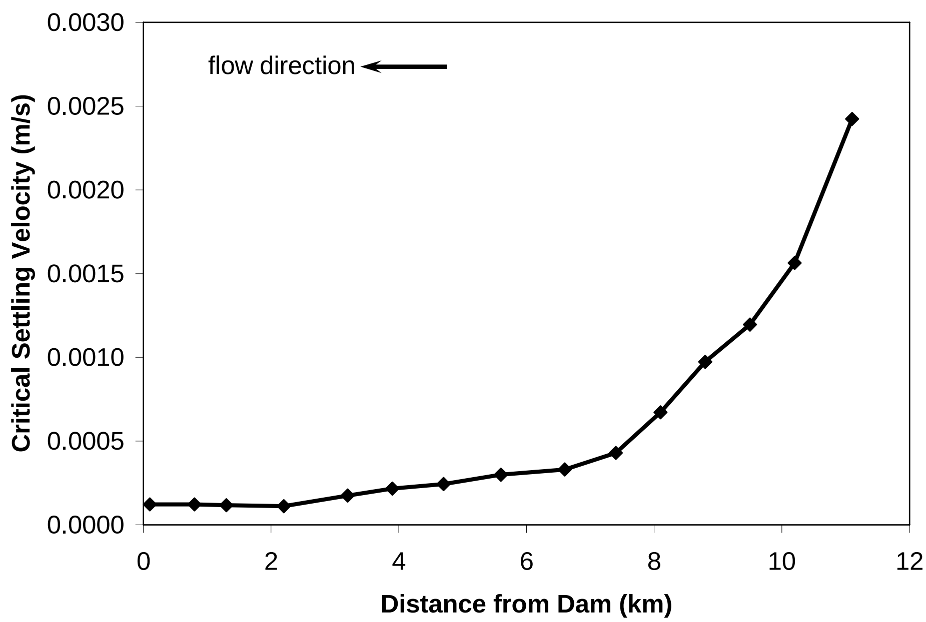


Figure 4. Calculated critical settling velocity for sediment particles to settle in Iron Gate Reservoir at 709 m pool level.

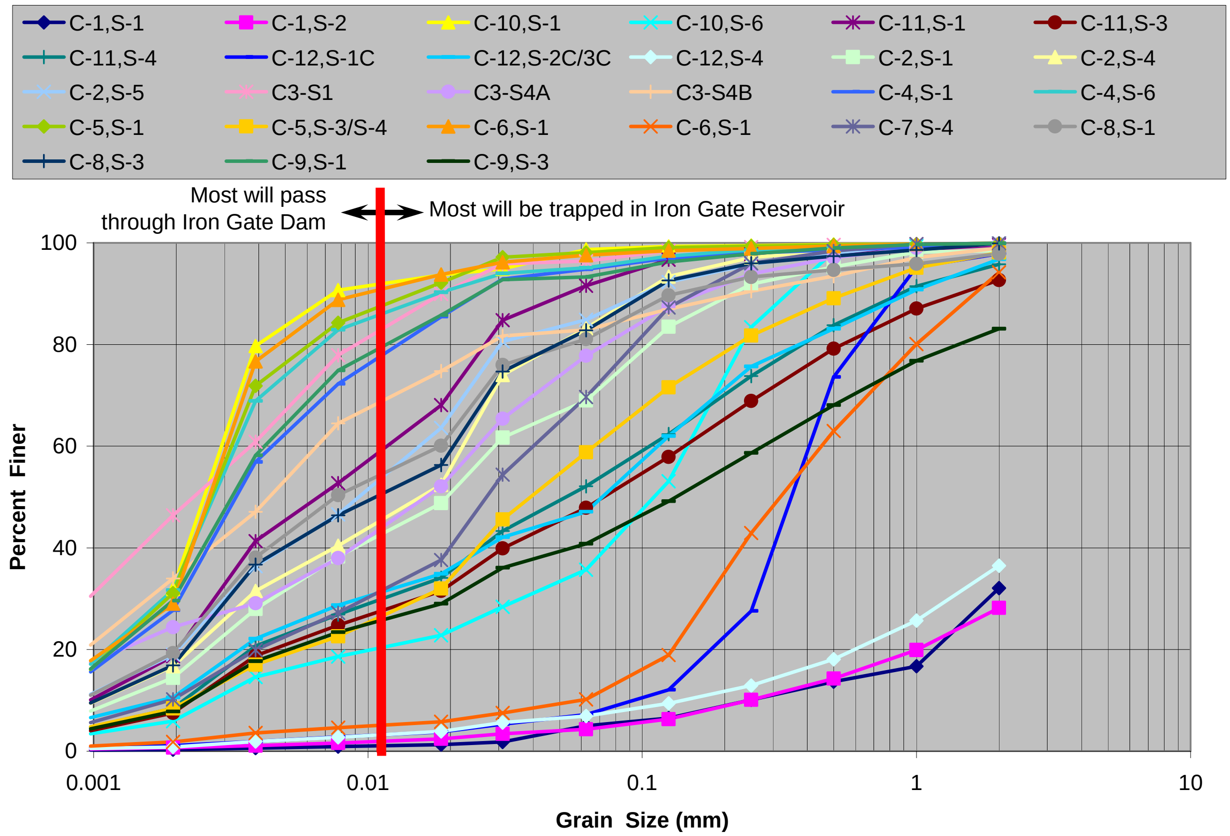


Figure 5. Grain size distributions of the sediment cores obtained by Shannon and Wilson, Inc. (2006) in Copco 1 Reservoir (there is no sediment deposit in Copco 2 and relatively small amount of sediment deposit in J.C. Boyle reservoirs). The critical particle size for settling in Iron Gate Reservoir is also presented as the vertical red line, showing substantial fraction of fine sediment will likely pass through Iron Gate Dam to the downstream reach. Legend above the diagram shows the location and layer number of the core. See Shannon and Wilson, Inc. (2006) for details.